Sedimentation rate in the North Basin of Bolinas Lagoon, California

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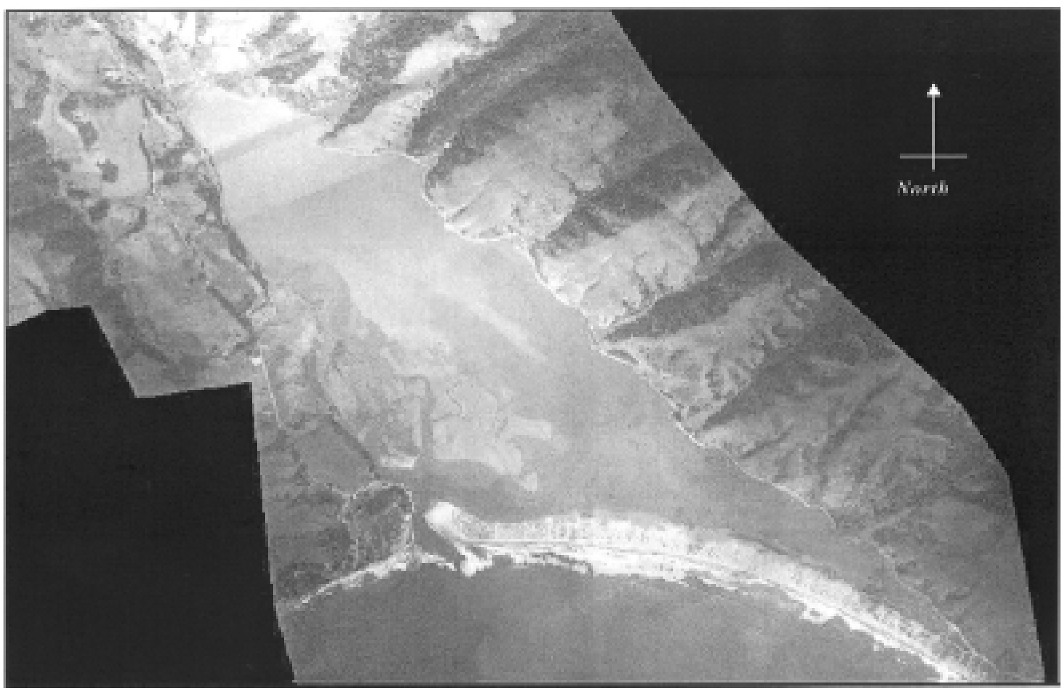
Abstract Bolinas Lagoon exists as a haven for birds and marine life as well as an aesthetic addition to the West Marin communities. The lagoon is decreasing in size and potentially will transform into a meadow. This transformation poses a management dilemma of whether or not to dredge the lagoon. This study was performed to determine the relationship between the sedimentation rate in the North Basin of Bolinas Lagoon to the population changes in the lagoon's watershed. In order to determine the sedimentation rate, sediment cores were extracted at the same sites as a previous set of cores (Knudsen et al, 1999) was taken. The 1999 core depictions and descriptions also are marked with C-14 dates. Knudsen et al.'s cores suffered from compaction but the core in this study resolves the compaction issue. The stratigraphy, composition, and volume of the most recent cores will be compared to the information provided in Knudsen et al study to determine the sedimentation rate in the North Basin.

Introduction

Twelve miles northwest of San Francisco, Bolinas Lagoon is one of the few lagoons on the California coast that has not undergone restoration. Over the past 50 years, there have been noticeable changes in the lagoon. Through aerial photographs of Bolinas Lagoon between 1942 and 1997, it is apparent that the area of land covered by water has decreased. (US Army Corps of Engineers, 2002) (Fig.1a-d). Currently in debate is the proposal to dredge the lagoon to avoid its transformation into a meadow (Williams and Cuffe, 1994). Bird watchers, homeowners, tourism businesses, developers, and ecologists are all interested in preserving the current lagoon and marsh ecosystems as Bolinas Lagoon is an important habitat for native fish, water birds and marine mammals.



(a)

(b)

(c)

(d)

Figure 1a-1d. Aerial photographs of Bolinas Lagoon from 1942(a), 1959(b), 1984(c), 1997(d), showing the below water sediment changes. (Us Army Corps of Engineers).

A typical lagoon is defined by a sand spit that separates the ocean from the lagoon, an inlet channel through the sand spit, freshwater inflow, channels, mudflats, marsh and upland (DeTemple, et al. 1999). Different areas of the lagoon are affected by fresh water influx, tides, inter tidal channels to varying degrees, therefore it is imperative that the lagoon be studied as a subset of systems.

A lagoon is an evolving ecosystem maintained through a balance of natural acts (as seen in Figure 2). Lagoon sustainability also depends upon the equilibrium between sedimentation, sea level rise and tectonics and often develops from an estuary valley to a lagoon followed by infilling creating a marsh or a deltaic-filled lagoon (Nichols, 1989). It is believed that the Bolinas Valley developed as a result of the Pacific and North American tectonic plates collision. As the ice caps melted, sea level rose creating a bay where there was once a valley. Through long shore lateral transport, suspended sediment moving south along the coast accumulated in the Southwest edge of the bay creating the sand spit that now shelters Bolinas Lagoon from the ocean.

In 1834, European settlement began in the Bolinas Lagoon watershed. Approximately 15 years later commercial logging began to take place and over the next 50 years vegetation clearing, grazing, road building and logging led to accelerated erosion and sedimentation (Wetlands Research Associates, 1996). It is rare that lagoon sedimentation rates are perfectly in sync with sea level change, but tectonics can cause immediate and drastic changes due to subsidence. Because the San Andreas Fault splits the lagoon in half, it is important to take into account the inevitable tectonic effect.

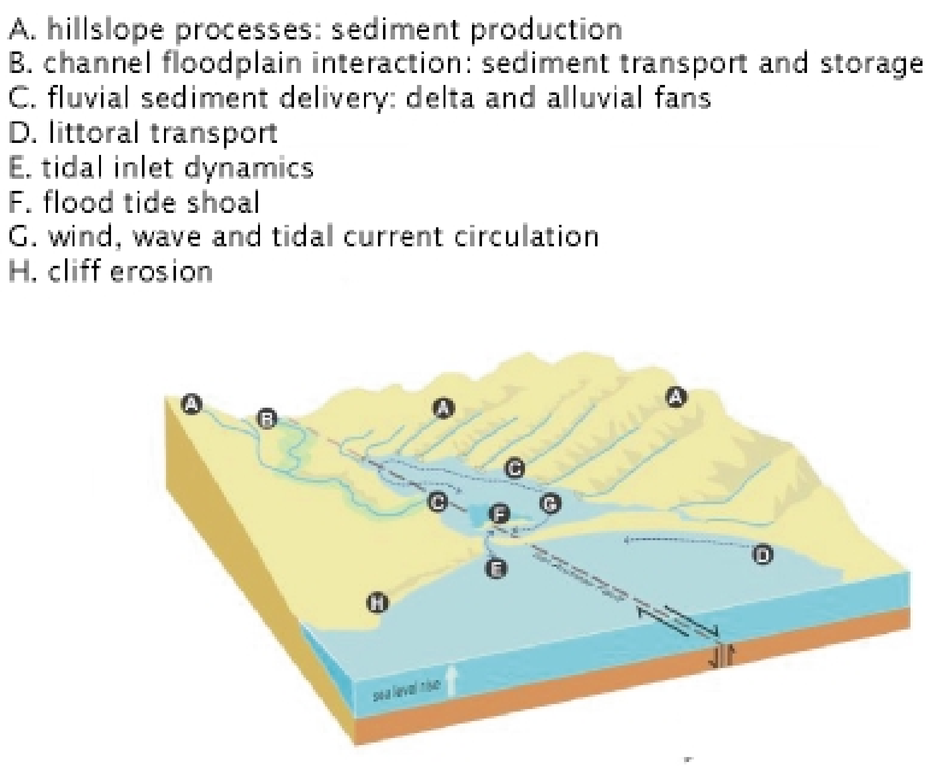


Figure 2: The physical processes affecting Bolinas Lagoon (Marin Open Space, www.marinopenspace.org/os_bolinaslagoonmgtplan.asp)

From Bolinas and Stinson Beach residents to developers and ecologists, many human interest groups are emotionally and/or financially invested in the future of Bolinas Lagoon. Dredging the lagoon would prolong the life of the lagoon, but may irreversibly damage the ecosystem through months of constant disturbances. Residents, tourists and businesses enjoy taking boats our in the lagoon and also use the area as a place to harbor small fishing boats. Bird watchers are always present on the shores of the lagoon enjoying not only the numerous species of birds, but the sunning sea lions as well. The lagoon also adds property value to the homes that have the beautiful, unobstructed view of the water and wildlife. Uncertainty of what irreversible damage can occur is of primary concern to ecologists.

Before deciding to dredge the lagoon, we should consider all possible proposals for the lagoon's future. For example, with a proper sedimentation management plan sedimentation rates could be slowed. This plan could eliminate the need to dredge while preserving the current ecosystem. In the event of dredging, sediment from the lagoon would be dumped close to shore. The extent of changes from this high load of suspended sediment just off the coast is unknown, but it will increase the amount of sediment deposited on nearby southern shores. The disturbance that will prevail during the reconstruction will include noise, habitat destruction, and traffic obstruction all at a high cost. There is no way to predict how the habitat will restore itself and if the variety and abundance of wildlife will return. Understanding the natural stages in the transformation of the land is important because we, as humans, struggle with our power and responsibility to act as stewards of our Earth while making subjective decisions on the future of our land.

The purpose of this study is to determine the sedimentation rate in the North Basin of Bolinas Lagoon by comparing previously collected data to my more current data. Knudsen et al (1999) took eleven cores in the North Basin and used fossil pollen from non-native plants and accelerator mass spectrometry radiocarbon analyses to identify, describe, and date stratigraphic sequences of peat, mud, sand and other materials. These cores were extracted by driving "aluminum irrigation pipe into the marsh to depths of 2 to 3 meters. Driving the cores into the marsh resulted in 20% and 40% sediment compaction" (Knudsen et al., 1999, p.11; from this point on will be referred to as Knudsen). Because the sediments were compacted, their volume does not reflect infill rates. By using a Livingston corer, which does not compact the sediment, my core accurately represents the true depth of each layer of sediment. The core for this study is a replicate of Knudsen et al (1999)'s 98 BOL D2 core with the actual depth of each layer of peat and mud. By using the C-14 dates and stratigraphic sequence derived by Knudsen et al. study, an accurate sedimentation rate for the North Basin of the Bolinas Lagoon can be determined.

Methods

All the cores extracted and studied by Knudsen et al. were taken from the North Basin. In order to use the carbon dates they determined for the different layers of sediment, I am re-sampling a core that was extracted for their study. I chose the site based on location and available C-14 dates and was able to extract one core. To locate the previously sampled sites I used a map provided in the Knudsen report (Knudsen, 1999). I determined the distance and angle of each site from an intersection that can be assumed unaltered since the date of the photograph. The benchmark used is the Southern most point of the intersection of Highway 1 and Bolinas-Olema Rd. A Tocpcon, total station survey device, located at the benchmark provided accurate horizontal and vertical distance as well as the angle from North for the coring site.

The Livingston corer is first lined with a clean plastic tube that keeps the core clean and easy to transport. Once a core is taken, the depth, date and location is marked on the ends of the tube. The key data for this collection is the depth of the different sediment layers. Knudsen et al's data for the depth of the sediments is irrelevant because of their method of extraction. Since the pounding of the tube into the sediment caused a range of compaction, their cores could not be used to determine sedimentation rates. My cores will be accurate in the measured depth of the core and the actual depth of the sediment layer in the North basin.

Once in the lab I cut the cores in half, lengthwise, to reveal the stratigraphy. I determined what each layer is composed of and I compared it to the stratigraphy of Knudsen's detailed drawings and descriptions. After determining the composition of my cores I drew a scaled representation of the different layers of sediment. I compared my drawings to Knudsen et al's to make connections between the sediment layers and the dates. Once I have a date for a specific layer, I can use the distance from the surface of the sediment of the layer extracted to determine the height that was deposited during that time block at that given site. For this data I assumed that the sediment is deposited evenly in the Northern basin of the lagoon.

Results

The core I extracted was taken in two parts from the same site as Knudsen's 98 BOL D2 core. The first push into the lagoon produce 93cm of sediment and the second core extracted another 97cm for a total of 190cm depth at site Bolinas Lagoon-A 05. The stratigraphy was visibly apparent as well as texturally, therefore creating an illustrative representation of the core was straight forward (Figure 3.).

Comparing my stratigraphic representation with Knudsen's in addition to using magnetic susceptibility data from M. Elizabeth Cock's 2004 cores and A Roger Byrne's 1995 and 2000 cores, I was able to obtain three depth/date correlations to determine three sedimentation rates.

Table 1. Calculated data from Bolinas Lagoon-A 05, Byrne and Cocks

Time Period	Amount of Sediment Deposited (cm)	Sedimentation Rate (depth/time)
1868-1942	41	0.55cm/yr
1943-1993	67	0.75cm/yr
1994-2005	9	0.82cm.yr

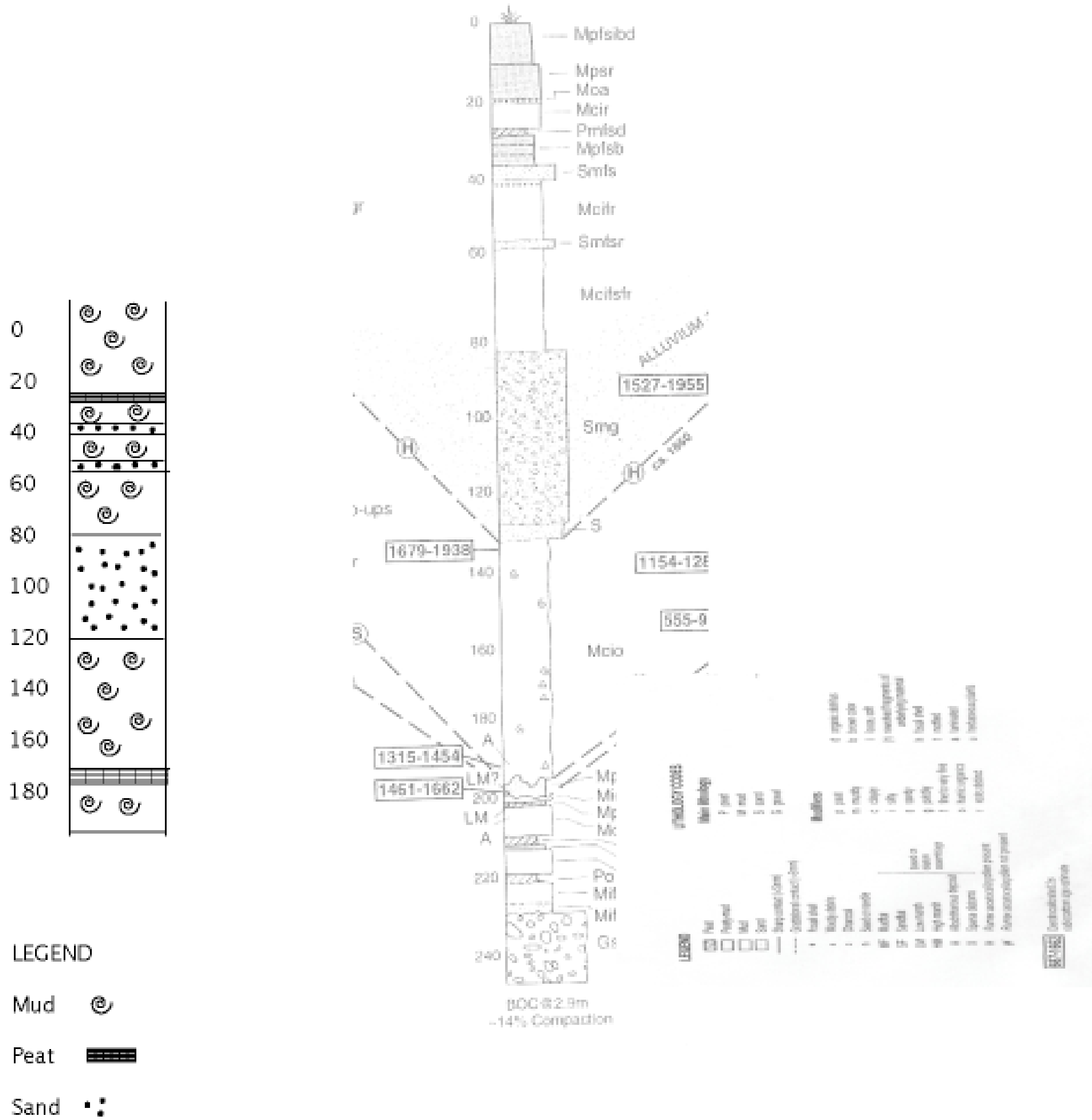


Figure 3. Stratigraphic comparison of Bolinas Lagoon-A 05 (left) and Knudsen's 98 BOL D2 (right).

Discussion

My data show that the fastest accumulation of sediment has occurred over the past 11 years at a rate of 0.82cm/year. Because the time interval is much shorter relative to the two earlier periods it is difficult to make any conclusions about the significance of the recent sedimentation rate. The sedimentation rates for the earliest intervals show a 36% increase in sediment accumulation during the fifty years following the 1868-1942 period. In similar studies, variations of sedimentation rates have been proposed. Joel Bergquist (1978) postulates there is no significant change in sedimentation rate between 1906 and 1976, while Peta Mudie estimated a rate of 0.25mm/yr between 1858 and 1975.

Although my data show an accelerated sedimentation rate in the North Basin of Bolinas Lagoon, it is apparent through the discrepancies in my data and that of Cocks, Mudie, and Bergquist that further studies must be done in order to get a better understanding of the evolution of Bolinas Lagoon. In this approach one could determine how the sedimentation rates have shifted in each area of the lagoon. For instance, the evolution of the lagoon from 1942 to 1984 and 1997 (Figure 1) clearly indicates that sediment accumulation in the Southwest section of Bolinas Lagoon is greater than in other areas. One plausible reason for such an occurrence is the drainage of Pine Gulch Creek into that area. Therefore, a holistic model of Bolinas Lagoon's evolution would give greater insight to the primary sources of sedimentation providing land management with a better idea of how to undertake the lagoon's future.

At this point I cannot draw any conclusions about the relationship between development in the watershed and sedimentation rates. I think it is important to consider the probable correlation between sedimentation rate and development because a properly designed management plan could effectively slow the infilling process. I recommend the lagoon be addressed as a collection of multiple systems defined by each systems primary sediment feeder. Such information would help pinpoint target areas of higher and lower sedimentation rates.

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